The Dynamic Behaviour of Corrugated steel plate lining in cut and Cover Tunnel as backfill material

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ABSTRACT

The seismic behaviour characteristics for the application of the Corrugated Steel Plate Lining in cut-and-cover tunnel are evaluated as several conditions for the backfill height, the cutting slope, and the relative density of backfill soil are changed.

The compressive stress which is calculated in the Corrugated Steel Plate Lining by the seismic load is decreased as the backfill height increases and the cut slope grows gentle. Also, the moment shows the tendency of decrease according to the increase of the backfill height. But in the case of the relative density of the backfill soil is small, the moment increases according to the increase of the backfill height and affects the dynamic behaviour characteristic. So it is considered that the relative density of the backfill soil is also the important point.

As the result in analyzing the seismic response characteristics of the reinforcement spacing of the Corrugated Steel Plate, the variation in the compressive force is hardly happened, but the moment and the shear force increase on the reinforcement spacing being narrow.

1. INTRODUCTION

1.1 Background and purpose of the research

Since Korea has many mountain territories, making a good lining in construction of highway becomes an important issue. Moreover, tunnel construction increases these days, because of an environmental issue. But people have been following old customs in domestic tunnel lining design without developing any new alternative material for lining.

Concrete, which is the most common material, has many problems in construction period, cost, and crack. These days many research centers like the Korea Highway Corporation recognize a need for developing new alternative materials and grow on interest in an application of corrugated steel plate in cut-and-cover tunnel.

But considering a construction policy and public opinion, evaluating not only domestic design provisions but also seismic design are needed to introduce corrugated steel plate into Korea. Tunnels are classified into the first class structure for seismic design by the standard of domestic seismic design. Therefore, in Korea, tunnels are required to be constructed with seismic design. But in Canada, evaluation provisions for earthquakes are lenient. Therefore, when introducing corrugated steel plate into Korea, it should be clarified whether the behavior characteristics of corrugated steel plate for earthquakes is fitted in the domestic design standard.

This paper evaluated dynamic behavior characteristic of corrugated steel plate lining

through dynamic time history analysis when applying corrugated steel plate to the lining of underground structures like cut-and-cover tunnels.

1.2. Research content and method

To analyze dynamic behavior characteristic of corrugated steel plate lining in cut-and-cover tunnel, dynamic time history analysis was conducted for non- reinforcement of 7.01mm thickness and EC-Rib reinforced corrugated steel plate, which is applied to two lane freeway tunnel's excavation section as Fig 1.

To do this, this research closely examined into stability and behavior characteristics of corrugated steel plate lining by changing conditions of embanking height, excavation slope's inclination, and backfill soil's ratio of compaction of cut-and-cover tunnel.

The research conducted time history analysis by using frequency domain analysis. The research used moderated rock as bed rock because most of mountain tunnels' rock is moderated rock. Using artificial synthetic seismic wave, dynamic behavior characteristics depending on degree of compaction of backfill soil, ground height of tunnel, excavation inclination of bed rock and reinforcement spacing of corrugated steel plate were analyzed.

Here, conditions of height of ground depth were these: First, backfill soil was constructed up to the minimum ground height(called 0.0D in this research for convenience) of corrugated steel plate structure; second, backfill soil was constructed up to a place where ground height is 0.5 time of a diameter of the tunnel(0.5D); Third, backfill soil is constructed up to a place where ground height was 1.0 time of a diameter of the tunnel(1.0D). Behavior characteristics for each of these conditions were analyzed.

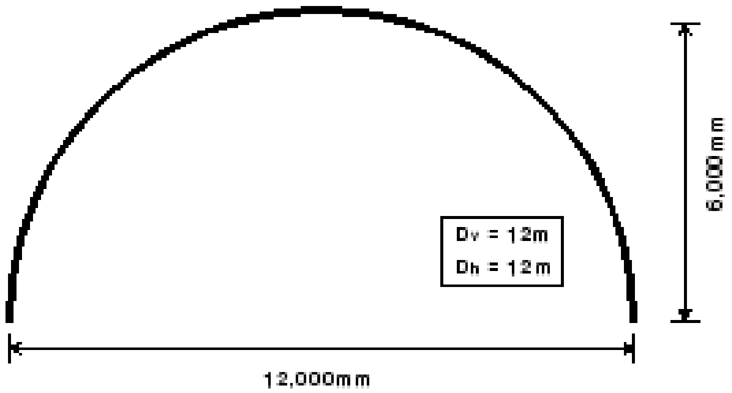

Figure 1. Section size of cut-cover tunnel

2. Analysis of numerical parameter

2.1. Interpretation program

Modal Analysis through Eigen Value Problem is commonly used for aseismic analysis. But for dynamic analysis of ground-structures, it is difficult to consider nonlinear characteristics of ground by using only Eigen Value Problem. Therefore, for underground structures, greatly affected by nearby ground's characteristics, finite element analysis should be performed after changing time history to Frequency domain. And then dynamic finite element analysis which operates Inverse Fast Fourier Transformation(IFFT), should be applied. By doing this, more reasonable result can be earned.

This research used AFIMAX as an interpretation program to perform seismic analysis for analysis of dynamic behavior characteristics of corrugated steel plate in cut-and-cover tunnel. Flush is a main solver of this program. Flush is an authoritative program used as a dynamic interaction analysis of a ground structure in USNRC, since it was developed in University of

California, Berkeley in U.S.A. in 1975. To perform by using this program was that first of all, free field ground response should be performed by using early estimated ground's shear modulus of elasticity and damping coefficient. This produced , adjusted by Equivalent Linear Method, and damping ratio. By using these, finite element analysis was accomplished. The curve, which Seed & Idriss had proposed, was used for strain-compatible curve of a ground in this method.

2.2. Interpretation modeling and boundary condition

To analyze dynamic behavior characteristics of corrugated steel plate, finite element mesh of soil-structure interation was used as picture 4 below. It was comprised of beam element(corrugated steel plate), backfill soil element, and Interface Element, which placed between backfill soil element and beam element. (Fig 2)

Generally in a case of Sb ground, comprised of rock more quality than moderated rock, amplification and a decrease of wave did not exist when applying seismic load to bed rock. Since there was little difference in design accelertion, seismic wave was applied for bed rock. Viscosity boundary was used in boundary condition of bed rock to make vibration energy delivered to the model. The vibration energy was restrained to be reflected from the right and the left side of the boundary side by using response boundary condition of the right and the left side of the boundary side in numeric value model.

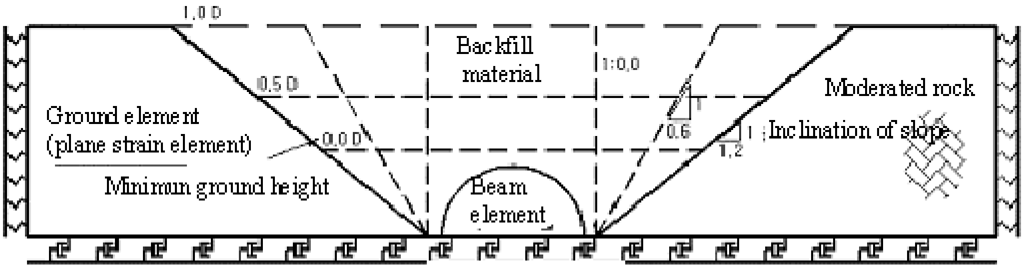

Figure 2. Dynamic section of corrugated steel plate in cut-and-cover tunnel

2.3. Computation of ground's dynamic material parameter

Shear modulus assessment method, by using binding strain of the ground is that binding strain of each depth is used in shear modulus assessment formula. So even same stratum has different shear modulus**.** Among many of sheer coefficient assessment methods, this research used assessing shear modulus by relative density formula which Seed suggested in 1970, to compute the shear modulus.

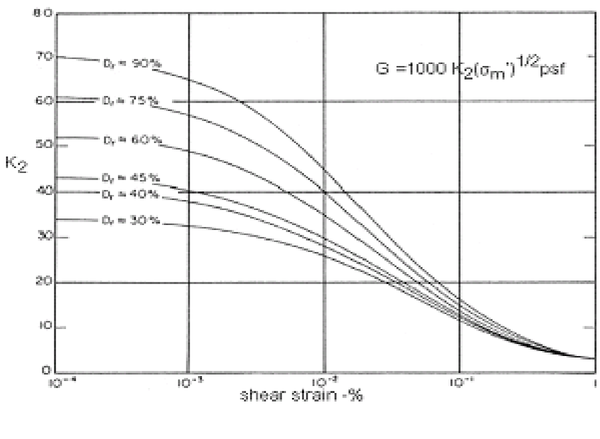

Figure 3. Stiffness vs. shear strain where Dr = relative density, σ'm = mean effective stress

Here, K is the coefficient for relative density (Fig 3), q is the binding strain of the ground.

Dynamic material parameter of backfill soil is shown as follows. Using Seed's coefficient for relative density(K2)(Fig 3), dynamic numerical analysis was conducted when K2 was 46, 64, 80. Sheer coefficient for moderated rock was applied for bed rock. In boundary side where the tunnel and the bed rock were tangent to backfill soil, the interface factor was applied. Seed's suggesting value was used for shear strain amplitude of equivalent linear method, shear modulust, and the relationship between shear strain amplitude and damping ratio.

2.4. Seismic wave selection

The most common artificial synthetic seismic wave producing methods are adjustment of existing earthquake record and production of artificial synthetic seismic wave by using inclusive function at time domain. The adjustment actual earthquake record method is an application of scale factor, which uses acceleration time history or Effective Peak Acceleration in velocity time history, to control earthquake. This method is convenient because it can earn artificial synthetic seismic wave by using existing seismic wave. However, it shows some differences from standard response spectrum, which is suggested in a real design.

Therefore, This research used artificial synthetic seismic wave, produced by using inclusive function at time domain. By using this artificial synthetic seismic wave, dynamic analysis was conducted. Following the domestic earthquake-resistant design standard, design response spectrum was written, setting moderated rock as a standard. This was shown in Fig 4.

In general, a mountain tunnel is the first class structure and is constructed on the ground, composed of rocks more quality than moderated rock. Therefore, the seismic wave was used in this research, setting moderated rock as a standard. Also, according to domestic earthquake-resistant design standard, earthquake district is classified into I district and II district. This research used district coefficient of district I, where stronger earthquake occurred, to made seismic wave. Also, by using SIMQKE, primitive artificial synthetic seismic wave was produced. After that, final artificial synthetic seismic wave which was fitted in NRC standard in U.S.A, was produced. This artificial synthetic seismic wave's spectrum and time history are shown in Fig 5. Effective Peak Acceleration(EPA)was 0.154g, earthquake duration time was 24 second, and primary frequence was 2.2Hz.

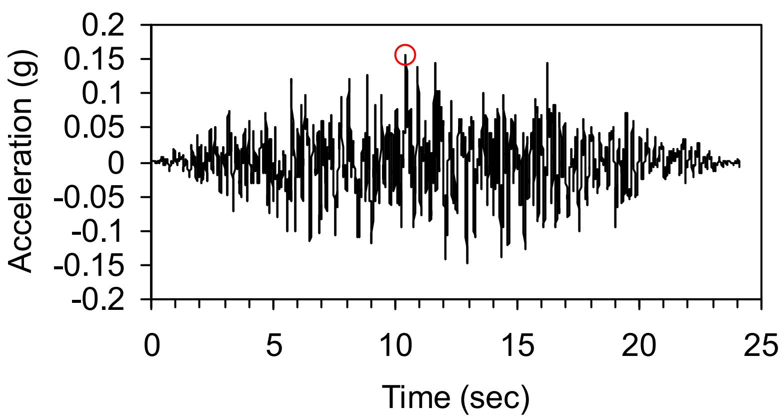

Figure 4. Time history curve of artificial seismic wave

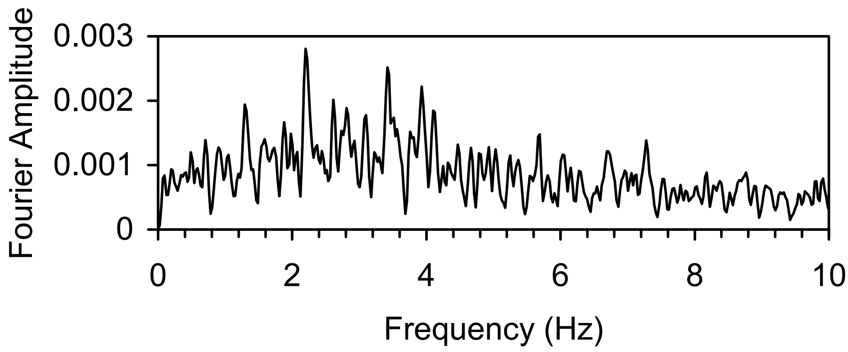

Figure 5. Fast Fourier Transform curve of artificial seismic wave

3. Numerical analysis

3. 1. Outline for analysis of numerical parameter

If eartheuake occurs at underground structures like tunnels, the result is different from structure on the ground. Tunnels, unlike from structure on the ground, are surrounded by soil or rock. Therefore, because of the surrounding ground's binding power, damping effect of earthquake is greater than that of from structure on the ground. Therefore, underground structures have far less dynamic response spectrum than structures on the ground.

By using artificial synthetic seismic wave, the research analyzed a case of when ground height was re-filled with soil up to the minimum ground height standard, when the ground height was re-filled with soil up to 0.5 time of a tunnel diameter, when ground height was re-filled with soil up to 1 time of a tunnel diameter for each condition of 1:0.0, 1:0.6, 1:1.2 of excavation inclination. Total 108 cases of when K2, a relative density, was 46,64,80 for different backfill soil's degree of compaction , were analyzed.

3.2. Behavior analysis using backfill soil's height

If the reinforcement spacing and degree of compaction were consistent (slope inclination, reinforcement spacing, coefficient for relative density were fixed), the behavior of corrugated steel plate lining for different ground height condition was shown in Fig 6-8. Both axial force and moment decrease, as ground height increases. The reason for that is damping effect for seismic load is big as depth of tunnel location increases.

However, when ground height increases from 0.5D to 1.0D, moment at tunnel lining shows an opposite result for relative density. In the case of when ground height increases from 0.5D to 1.0D, the minimum moment decreases by 9% if relative density(K2) is 80. However, if relative density(K2) is 46, 64, the maximum moment increases by 17%, 10% for each. According to this result, lining moment, which arises from seismic load, is greatly influenced by degree of compaction of backfill soil. When seismic load occurs, degree of compaction is an important factor to decrease compression(압축력), which arises from an increase in ground height. The binding effect of underground structure increases as relative density has high density. As the relative density is low, the load of the loose ground, rather than binding effect, acts on.

In the case of when excavation inclination of ground is 1:1.2 and 1:0.6, axial force and the maximum moment arise similarly. However, moment occurrence according to an increase in ground height clearly decreases in 1:1.6 case more than in 1:1.2 case.

When the excavation inclination of ground is vertical(1:0.0), maximum axial force does not

change(picture 15a) and the maximum moment decreases as ground height increases. At this time, all member force are not affected by relative density and shows the same result in a given condition. According to this result, the influence from relative density is little when the excavation inclination is close to the vertical. This is because the backfill soil, which surrounds the tunnel, is bound by the surrounding ground.

3.3 Analysis by using excavation inclination of ground

Influence of ground, which has bigger rigidity than backfill soil (influence of ground rigidity due to the seismic wave) on the tunnel was analyzed. Numerical analysis for each condition of excavation inclination was conducted and the result was analyzed.

The maximum axial force for the different excavation inclinations is biggest when the inclination is 1:1.2. The change of axial force is subtle until the inclination is 1:0.6. But when the excavation inclination is 1:1.0, the axial force rapidly decreases. According to this result, the more vertical the excavation inclination is, the smaller the influence of the ground height is. This is because the surrounding grounds bind the backfill soils.

The maximum moment decreases as the excavation inclination is close to the vertical. Comparing the 0.5D ground height and 1.0D ground height, the 0.0D ground height gradually decreases. This is because the smaller ground height is, the smaller the binding effect of the surrounding ground. As ground height increases, seismic energy greatly decreases, because of the binding effect of backfill soil. However, when ground height is close to 0.0D, the reason for decrease in the maximum moment is that ground vibration characteristics can be delivered to tunnel without filtering. In this case, it is not because of the binding effect of the surrounding ground.

Therefore, in corrugated steel plate lining, the seismic performance increases, as the excavation slope is steep.

3.4. Analysis by using reinforcement section

Underground structures like cut-and-cover tunnel are surrounded by soil and rock. So the structure and the surrounding ground does not move, when seismic wave occurs. Considering the soil-structure interaction effect is important for proper seismic analysis in this situation. Also, the relative rigidity of the ground and the structure dominantly affect the earthquake characteristics of the underground structure.

Generally, in a case of when proper load act on the underground structures, the satisfying result for stability of the structure will be obtained, as member rigidity is big. In a case of when dynamic load like erthquake act on the underground structures, the inertial force increases as thickness of a section increases. Therefore, numerical analysis was conducted through changing reinforcement spacing of corrugated steel plate to understand the behavior of cut-and-cover tunnel depending on relative rigidity of the ground and structures.

According to the result, axial force is same for the different reinforcement spacing of corrugated steel plate. moment increases , as the reinforcement spacing is narrow and the a lot of reinforcement for concrete is established. The concrete part of the corrugated steel plate acts by its own weight so that the inertial force arises. This leads member force to increase, because the inertial force increases. The maximum moment occurs at 1:1.2, where the excavation inclination is most gentle. As the excavation inclination is close to the vertical, the maximum moment decreases.

4. Conclusion

By conducting dynamic time history analysis, the dynamic behavior characteristics of corrugated steel plate in cut-and-cover tunnel is evaluated. The summary of the result is

below:

(1) As height of backfill soil increases, the compressive stress, which arises from seismic load, and moment decrease. But if the relative density of backfill soil is small, moment increases as ground height increases. Therefore, degree of compaction of backfill soil, beside groung height and excavation inclination, is an important factor to affect dynamic behavior characteristics of corrugated steel plate lining.

(2) As slope is gentle, compression and moment from seismic load increase. However, as excavation slope's inclination is steep, compression, which arises from seismic load, and moment decrease. Therefore, in cut-and-cover tunnel's lining, which corrugated steel plate is applied to, seismic performance increases, as excavation slope's inclination of groung is steep.

(3) Analyzing tunnel's earthquake response characteristics for different reinforcement spacing, change of compression does not occur at all, but moment and shear force increase, as the spacing is narrow. This is because the inertial force increases as the reinforcement of concrete increases.

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